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TECHNOLOGICAL RESTRICTIONS OF LIGHTWEIGHT LATTICE STRUCTURES MANUFACTURED BY SELECTIVE LASER MELTING OF METALS

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S u m m a r y

Selective Laser Melting technique is one of the additive manufacturing methods. The paper presents the summary of technological problems and restrictions resulting in the production of lightweight lattice structures by this technique. All the cases applies to the device SLM Realizer II 250 running the software Controler for Realizer SLM/STL.

Keywords: SLM, rapid manufacturing, selective laser melting, lightweight lattice structures

Ograniczenia technologiczne w wytwarzaniu konstrukcji ultralekkich metodą selektywnego stapiania laserowego metali

S t r e s z c z e n i e

Selektywne topienie metali wiązką lasera należy do metod obróbki przyrostowej. W pracy przedstawiono analizę problemów technologicznych oraz ograniczenia w procesie wytwarzania metodą selektywnego topienia lekkich konstrukcji ażurowych. Badania doświadczalne prowadzono za pomocą urządzenia SLM Realizer II 250. Stosowano oprogramowanie sterujące Controler for Realizer SLM/STL.

Słowa kluczowe: SLM, szybkie wytwarzanie, selektywne topienie wiązką lasera, ażurowe konstrukcje ultralekkie

1. Introduction

Selective Laser Melting (SLM™) is a generative technique grouped in Rapid Manufacturing range derived from Rapid Prototyping technologies. During SLM, metal (or alloy) powder is selectively melted in horizontal areas, slice by slice. „Selective" means that melting process is realised only in areas included for scanning. The element is generated slice by slice. Virtual model is generated from CAD system, as an STL file, and prepared for melting by a special, dedicated software, and then uploaded to a machine controller.

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Preparation for melting process includes generation of support structures and division of the element vertically into slices.

Selective Laser Melting is getting to be a common manufacturing technique, used in the wide spectrum of scientific and industrial applications. Intensive scientific research concern application of SLM to: manufacturing of implants form biocompatible alloys and personalised medical equipment [1-4], manufacturing of composites and nanocomposites [5, 6], generating the fully controlled lattice ultralightweight structures [7]. SLM is applied as well to production of special tools used in different manufacturing techniques, like conformal cooling systems for injection moulds and punches & dies for plastic working [8]. The possibility to manufacture almost all geometric structures and shapes as well as wide spectrum of different metals and alloys used for melting process results in the growing of number of applications coupled with constant improvement of SLM technology and productivity by means of increasing research on this technique. One observes a lack of geometrical accuracy an surface quality, because of characteristics of the process of melting, but common laser manufacturing applications, like cutting [9, 10] also generate geometrical errors and surface roughness.

This paper points out some of SLM technological problems, which restrict application of SLM technology for manufacturing ultralightweight lattice structures with calculated and controlled inner geometrical structure. Described observations concern specific SLM machine, Realizer II 250, equipped with 100W laser and working space 250x250x200 mm. The software, which controls this machine is „Controler for Realizer SLM/STL".

2. Modelling restrictions

Usually software for preparing computer models in generative manufacturing applies STL format. This format was elaborated by Albert Consulting Group for 3D Systems company in 1987 [10] and is intended to upload model generated from computer software to stereolitography machines. Basing on the bibliographic study one could conclude that STL abbreviation comes from name of the *stereolitography* process, but it means Standard Tessellation Language. STL files apply triangles, connected at boundaries as representation of 3D objects. They contain only information about a surface of a 3D object. The surface is interpolated by flat triangles of different sizes. Dimensions of triangles depend on given size restrictions (accuracy of STL) and on geometry and complexity of the 3D model. Density of triangles is closely related to the given geometry of the file size. For instance for uniform 3D objects, like sphere with diameter 10 mm presented in Fig. 1, triangle accuracy is set to 0.02 mm (Fig. 1a) and 0.001 mm (Fig. 1b). Lower accuracy model is represented by 2400 triangles and the size of the model is 118KB. The model with better smoothness is represented by 49506 triangles with the size increasing up to 2418 KB.

a) b)

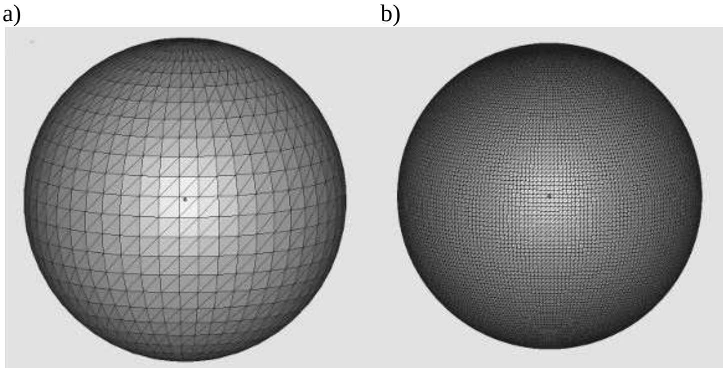


Fig. 1. STL representation of rough (a) and smooth (b) surface of sphere

Number of triangles representing 3D models is not problematic when simple parts are prepared for generative manufacturing. However, with increasing geometrical complexity it starts to be a real restriction, not only because of the size of the file, but also due to processing problems. Software for preprocessing part for additive manufacturing process divides STL model into consecutive slices. Each of slices is a XY map for scanning by generative process. In the case of SLM, software generates a path for a laser beam for each slice. This software is very sensitive to density of triangles and the number of areas to maintain in each slice. Therefore generating paths for an extremely complex geometrical object often fail because of the software system error. This is also caused by digitalising errors of already digitised geometry (dual digitalisation).

Ultralightweight lattice structures, due to their specific geometrical complexity, are very good examples causing preprocessing problems. High geometrical complexity of lattice structures causes a great number of individual areas in each slice. This number is very problematic on STL decomposition stage, from which a group of errors is generated. Also control computer is not capable on transforming a large number of individual areas which cause process break or stop due to error. Therefore an intensive experimental research is needed to elaborate an optimal geometrical accuracy for such structures.

3. Part size limitations

One of the SLM process parameters is a laser path interval. This interval (Fig. 2) is calculated to obtain full melting of a given area of a slice.

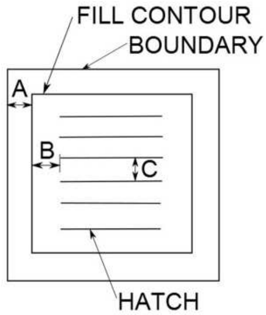


Fig. 2. Components of the laser path and distances between them (A, B, C)

Laser paths are divided into groups:

- Outline of whole area,
- Local area contour,
- Scanning area.

Path intervals are precisely calculated. Assuming that each area must include a boundary, a contour and at least one internal path, estimating the minimum dimensions of melted area is enabled. Standard melting parameters for titanium powder suggested by a manufacturer define path interval as 0.12 mm. The calculated minimum with of the melted area is approximately 0.48 mm. Assuming volumetric energy density as a resulting parameter enabling to obtain a given melted structure density, the following equation is presented [9]:

$$\varepsilon = \frac{P}{v \cdot h \cdot d}, \ \mathrm{J/mm^3} \tag{1}$$

where: P – laser power, W, v – scanning velocity, mm/s, h – path interval, mm, d – slice thickness, mm.

Scanning velocity could be formulated as follows:

$$v = \frac{b}{t}, \ \mathrm{mm/s} \tag{2}$$

where: b – distance between scanner dots which are building path, mm, t – exposition time in one point, s,

Using these equations it is possible to lower path interval and adapt other parameters, in order to obtain unchanged volumetric energy density. Additionally in order to obtain the path overlap ratio suggested by a manufacturer, laser spot size should be lowered respectively. Lowering laser spot size will help to avoid overlapping a whole paths and multiple scanning of the area, enabling the same, complete melting of the whole slice cross section. Because SLM device used in this research is not capable of processing paths distances below 0.025 mm, minimum melting area width is 0.1 mm.

4. Supporting elements and associated restrictions.

There are different types of supporting geometries (Fig. 3) in SLM technology which are built on a base plate to enable proper generation of a given model.

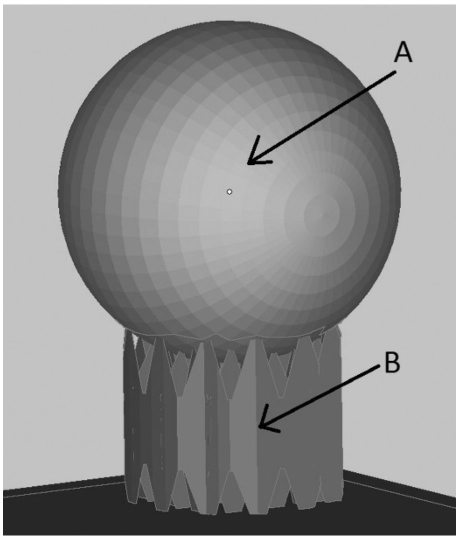


Fig. 3. Part (A) and supporting geometry (B)

Support bridges built below a model, between the model and base plate, the readymade model part are necessary to be cut off. Removal a part from the base plate could be also carried out with application of a wire EDM technology. No additional machining allowance on the part is needed. Support has to be generated also in case of angled geometry, when angle differs more than 45 deg from the vertical direction. In such a case there is no possibility to overlap melting slices with enough stiffness to carry the rest of generated geometry or to avoid the balling effect. Vertical support bridges, mostly bars, are generated to support geometry which will be overbuild above. Loss of supporting geometry could also lead to thermal deformations caused by different cooling speed of geometrical elements of structure, as shown in Fig. 4a. This decreases geometrical accuracy of the whole element. Additionally, cascading effect caused by deformations occurs. Deformed parts of former slice destroy powder slider, made of elastic material, which causes inaccuracy in next slices (Fig. 4b). Deformed geometrical parts, manufactured in former slices simply start to stick out. Error is potentiated consecutively both by destroyed powder slider and thermal effects. It may lead to a complete demolition of a powder slider and stopping of the whole melting process. The element is usually so deformed, that is completely unusable.

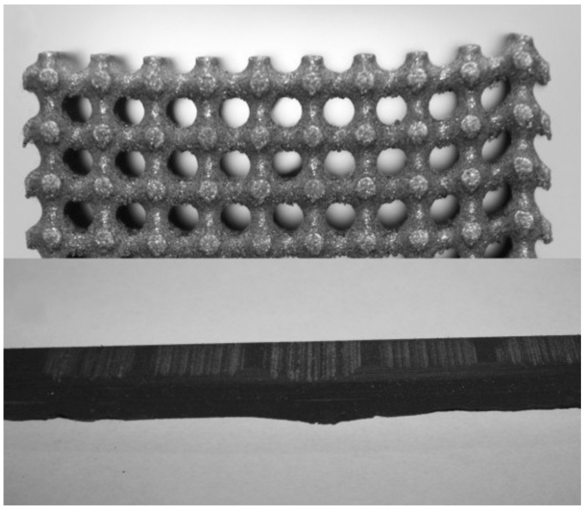
a)
b)


Fig. 4. Element with shape error a) and destroyed slider (b)

5. SLM process stability limitations

Metal powder from a main container is transported to a machine feeder by gravity forces. Machine feeder located in a processing chamber together with powder slider moves powder horizontally above a former slice to prepare a new melting cycle. Proper powder level is automatically controlled by sensors, which cause refilling of a machine feeder from main container. When the machine feeder is empty and could not be refilled, the process stops. The machine, used in this research, has no possibility to detect if metal powder was refilled evenly by width of machine feeder. Moreover it is impossible to check if the machine feeder dispenses powder evenly on a slice. If powder is dispensed only on a part of the slice, manufacturing errors occur. No new slice is being filled with powder and melted, but former slice is being remelted. In some cases the model is only partially generated, which can cause a collision of the part with the feeder and the powder slider, and consequently stop the process. Due to instabilities of manufacturing process, this method of Rapid Manufacturing is not suitable for unoperated, scheduled manufacturing and remains still in R&D phase.

6. Conclusions

Manufacturing of lattice ultralightweight structures by Selective Laser Melting is limited by variety of different conditions. This limitations strongly influence the possibility to manufacture complex regular and irregular structures.

There are limitations and restrictions. Regular restrictions are comparatively easy to estimate and predict i.e. STL size, angles of elements, open structures for emptying powder etc. The most unexpected are stochastic limitations, caused by low repeatability of the process and stochastic factors. One of them are thermal influences on geometrical accuracy and shapes of structures. These problems are hard to predict and estimate, because the number of stochastic factors exceeds regular ones. Machine errors are also unwanted, but could be fixed by mechanical an electronic improvements.

Consecutive research work concerning manufacturability of different structures with application of SLM structures are foreseen to be continued.

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